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THE GLACIAL FEATURES OF THE ST. CROIX DALLES REGION[1]

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Lying partly in Wisconsin, partly in Minnesota, this region has claimed the attention of the surveys of both states and is covered in their reports by general descriptions, in common with the adjacent regions. Because of their clearness and grasp of the salient points, the accounts to be found in Vol. III of the *Geology of Wisconsin* relative to the main movements of the Superior glacier in the northwest section of that state, form an excellent introduction to a detailed study of the St. Croix Dalles quadrangle. The Kewatin glacier, whose drift barely crosses the river into Wisconsin, has fallen to the Minnesota geologists to investigate. The differentiation of the glacial deposits of the last epoch into the red and gray drift, whose upper, oxidized portion is spoken of as the yellow till, appears in the works of Winchell[2] and Upham[3]. More recently a part of the Dalles quadrangle has been subjected to a closer, detailed investigation by Dr. Berkey,[4] who describes, among other aspects of the Pleistocene, the two drifts, the erosion of the St. Croix channel, and the river terraces. In that article the view of the Minnesota geologists, that the ice-sheet of the red drift advanced across the region from the northeast, is entertained.

The topography of northern Wisconsin, in so far as it was molded during the last glacial epoch, was due to the work of glaciers from the Labrador ice-cap. But over a large part of Minnesota the surface drift dates from an invasion of the Kewatin ice-sheet from the northwest. The Labrador ice arrived first, covering much of Minnesota; subsequently its deposits were buried by the advance from the northwest. The eastern limit of the Kewatin invasion was reached near the St. Croix River, in the vicinity of the Dalles.

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[1] My first acquaintance with this region was made as a member of the field class of Dr. W. W. Atwood in July, 1904, at which time the views of Dr. Berkey, and the Minnesota geologists, relative to the formation of the red drift by a movement from the east, and of the gray drift by a movement from the west, and related interpretations, were assumed to be correct, and made the basis of our working hypotheses. At the close of the work, however, some of the interpretations were unsatisfactory. After spending an additional month in further study under a wider range of alternate hypotheses, I have reached the conclusions set forth in this paper.

[2] N. H. Winchell, *Geology of Minnesota*, Vol. I, p. 126.

[3] Warren Upham, *ibid.*, Vol. II, pp. 399–425.

[4] C. P. Berkey, *American Geologist*, Vol. XX (1897), pp. 345–83.

The St. Croix Dalles quadrangle comprises those portions of Polk County, Wis., and Chisago County, Minn., which border on the St. Croix River between latitude 45° 15′ and 45° 30′, and longitude 92° 30′ to 92° 45′. The river, with some windings, flows generally south through the western half of the quadrangle. On opposite banks are the centrally located towns of Taylor's Falls and St. Croix Falls, while seven miles downstream is Osceola, Wis. The region as a whole is covered with a thick mantle of drift, which effectually hides the rock formations, except where uncovered by the river, or where an occasional boss of Keweenawan trap protrudes with a *roche moutonnéed* surface.

There are not only two separate drift-sheets represented as surface formations in different parts of the quadrangle, with the likelihood of an older till below, but the two dissimilar drifts both belong to the Late Wisconsin. The Dalles region is peculiar in having the eastern half of the quadrangle glaciated by the Labrador ice-sheet, and the surface of the western part covered by till from the Kewatin sheet. The glacier from the former source was the first to appear as a vigorous sheet, spreading heavy deposits of drift over the entire area. First to come, it was the first to go. It had retired quite beyond this region before the weaker development from the Kewatin gathering ground, spread to the St. Croix River. This ice crossed into Wisconsin less than a mile at St. Croix Falls, though about four miles in the vicinity of Osceola; but it quickly withdrew, leaving in most places only a thin covering of Kewatin drift. To get an idea of the work and relative importance of the two ice-sheets, conceive of the glacier of the red drift, or the Superior (Labrador) glacier, as a vigorous, long-enduring sheet, which produced most of the present topography, and of the glacier of the gray drift, or the Kewatin glacier, as a thin, transient advance of ice, which left as its record only a gray veneering of the red hills.

THE WORK OF THE SUPERIOR GLACIER

Whatever older drift there may be in this region has been so deeply buried under the thick Late Wisconsin deposits that no certain evidence of it was seen. The oldest glacial deposit thus far found is the red drift of the Lake Superior glacier. The first characteristic of this drift to catch the eye is its unusually red color, due to the presence of much ferric oxide. The unaltered till is very red; the stratified deposits from which the water has removed part of the coloring matter, less so. Often the surface layer has been partially leached of its ferruginous compounds, which have concentrated below, leaving the soil a brownish color. Another distinguishing characteristic of this till is that it is prevailingly sandy, and only locally clayey, signifying that the path of the ice advance was over an extensive sandstone and crystalline rock area, and that little limestone or shale was encountered. Of like import is the fact that, while there is the lithological heterogeneity characterizing glacial deposits, the pebbles are confined to a group of rocks chiefly of igneous origin, such as diabase, basalt, serpentine, various porphyries, granite and crystalline schists, together with sandstone. Limestone pebbles are conspicuous by their absence. The basalts predominating, the till may be described as a reddish sandy formation containing chiefly dark-colored igneous pebbles and bowlders. The source of this material is the Lake Superior region, the reddish sands coming from the Lake Superior Potsdam and Keweenawan sandstones, which are similarly tinted. Some of the red coloring-matter was also probably derived from decomposed ferruginous igneous rocks.

The movements and path of this ice-sheet are known from previous investigations to be these: The great ice advance from the Labrador snow-fields in the last Wisconsin epoch separated, west of the Soo, into two principal parts—one developing into the Michigan and Green Bay glaciers, which deepened the pre-existent valleys they entered, and partly formed and partly molded the troughs for the bodies of water which now bear these names; the other, similarly fashioning the Lake Superior basin, pushed on to the southwest, and formed the Superior and Chippewa glaciers. The Superior glacier, emerging from the Duluth finger of the Superior basin, deployed over much of Minnesota, and, spreading on its left flank in a southeasterly direction across the St. Croix, advanced some distance into Wisconsin.

Topography.—In this region the topography, with the exception of postglacial erosion by the river and a few minor streams, is largely

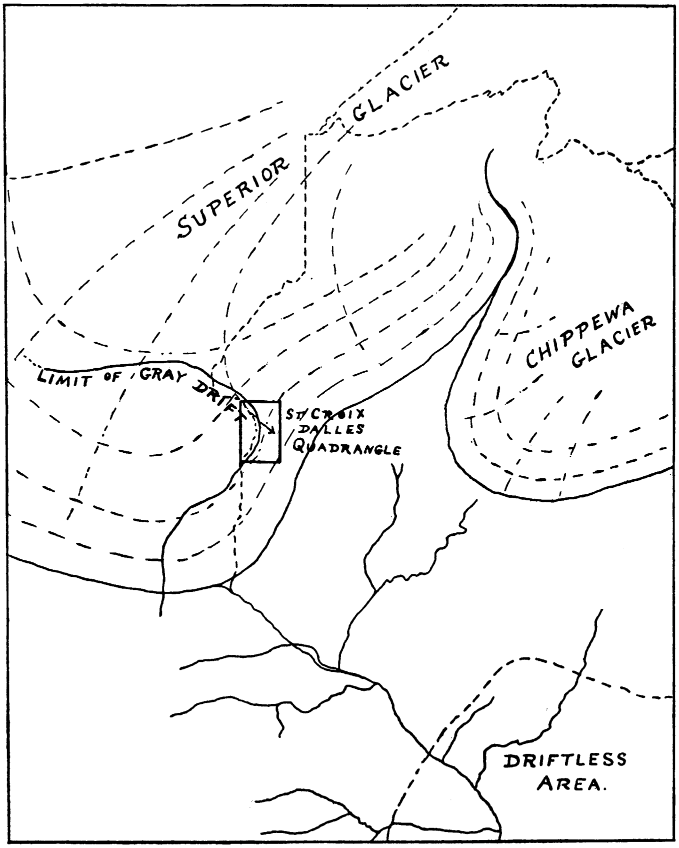

FIG. 1.—Sketch map, showing the general relations of the area of the St. Croix Dalles quadrangle. Data from maps of Wisconsin and Minnesota State Reports.

the work of the ice of the red drift. In the western part the covering of gray till, and the leveling action of the ice which made it, have modified the original red surface somewhat, though not enough to disguise it effectively; in the eastern portion it remains unaltered, so far as later ice advances are concerned. The most prominent features of this topography are three roughly parallel, or concentric terminal morainic ridges which, running northeast and southwest across the quadrangle, mark successive halts in the glacier's retreat. These may be termed in the order of their ages, the Alden, St. Croix, and Franconia recessional moraines. (See map.) Splendid outwash and pitted-plain topography, especially east of the St. Croix ridge, together with some ground moraine, appear between these morainic belts.

The Alden moraine.—To the oldest of the three terminal moraines which come within this quadrangle, as I interpret them, I have given the name Alden, from the township on the Dalles map in which it occurs. Only a small portion of the big moraine is included in the Dalles sheet, whose southeast corner it crosses. In this neighborhood the axis of the belt apparently runs nearly northeast and southwest, but a short distance beyond the edge of the sheet it must quickly turn nearly due north (as the St. Croix terminal does), for the Alden moraine is found as a wide belt of alternating hummock and kettle, about two miles off the map, northeast of Deer Lake. Just how far east of this belt the outermost terminal moraine of the Superior glacier lies, I am unable to say, though it cannot be a great distance.

While the ice-front oscillated back and forth across this Alden belt, a rough ground-moraine topography was being formed under the body of the glacier to the west. Later, when the ice-edge was at the St. Croix recessional, much of this rough country was covered by outwash. This is particularly true of the northern portion, where only the higher hills of ground moraine have escaped the covering of stratified deposits. But from Sand Lake south, for reasons which will be brought out later, not only the hills, but the great hollows as well, remain. Some of the land appears rather rough for ordinary ground moraine, but it must be borne in mind that this area lies between two adjacent terminal moraines, and that all of the intermediate ground might be broadly included in a comprehensive terminal belt. That the high-hill and lake-basin topography was the type to be seen in the northeast portion of the quadrangle before the outward streamlets began their work, seems probable.

The St. Croix moraine.[1]—After a period of melting faster than the glacier advanced, according to my views, equilibrium was again

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[1] Name given by Dr. Berkey, *American Geologist*, Vol. XX (1897), p. 360.

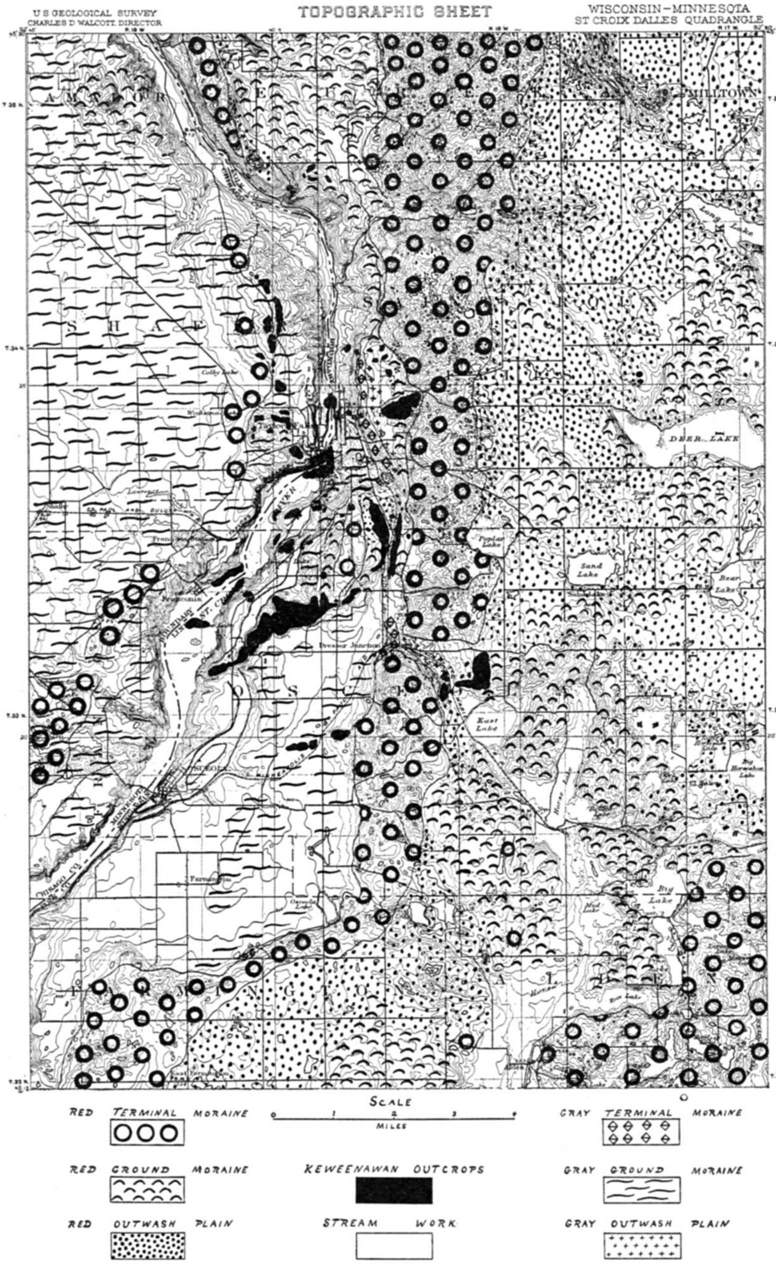

FIG. 2.—The geology of the St. Croix Dalles quadrangle. The Cambrian, which outcrops at points in the bluff of the St. Croix River, is not shown.

roughly established with the ice-front six or seven miles farther west, where the St. Croix moraine was piled up. This belt appears on the quadrangle about midway of the north margin, from which point it runs nearly straight south for ten miles to Dresser Junction, where it is cut in two by a gap. Beyond the gap it continues south for four miles, and then, as a much narrower strip, turns southwest, becoming wider in the extreme southwest part of the quadrangle. (See map.) In width, the belt varies from three miles in the northern portion, to about half a mile in the Township of Farmington. Like the older moraine, its concave side faces west-northwest. It is exceedingly rough and choppy, abounding in hummocks and kettles, knobby ridges, and blind valley depressions, the whole heavily overgrown with small trees and underbrush. The noticeably different aspect of the ridge when approached from the east and from the west is worthy of mention. On its eastern side the moraine merges into a smooth plain dipping gently away from it. There is no steep descent, nor are the moraine hills very much higher than the plain. On the west side, however, a steep declivity along the entire edge of the belt gives it an abrupt, ridge-like appearance. The hills in many places rise 200 feet above the lowland to the west. The significance of this marked difference will be readily understood in connection with the formation of the moraine and its outwash plain toward the east.

The St. Croix outwash plain.—Most of the region between the St. Croix and Alden moraines, with the exception of some hills of ground moraine which stand up above it, and an area near East and Horse Lakes which was never covered by outwash, belongs to the St. Croix outwash plain. With an altitude steadily diminishing to the east and southeast, the plain fades out in the neighborhood of the Alden terminal. East of Long Lake it reaches, and has even buried, some of the lower slopes of this ridge, over six miles from the ice-front at the St. Croix stage. But in general, east of the edge of the map, the outwash development is weak, and the underlying ground-moraine topography becomes more and more pronounced. The smoothness of this gravel plain, its rise near the crest of the moraine, its gentle slope to the eastward, and its mergence into drainage tracts in that direction, furnish the grounds for my interpretation of it as an outwash sheet formed when the glacier stood hard against the western side of the St. Croix moraine.

The surface of the plain is everywhere covered with a fine grayish-brown loam, free from stones, which hides the stratified material. The stratified deposits beneath are of variable thickness, from several scores of feet, as shown by some of the wells, down to two or three feet in road-cuts. While exposures are generally uncommon in the outwash plain and good sections rare, a few of them reveal typical red till underlying the sands and gravels. It is in these that the difference in coloring of the stratified and non-stratified red drift is so noticeable. Along some of the roads in this wide belt, red till appears in some places without any stratified material in sight. These patches are found to be above the level of the surrounding outwash plain on slight eminences which escaped the depositing streamlets. Such isolated hills of considerable size occur northeast of Poplar Lake, and both north and south of Deer Lake. A feature which quickly catches the eye is that on the ground-moraine areas large bowlders are numerous, whereas they are nowhere to be seen on the outwash plain.

One of the pronounced features of the outwash is the pitted-plain development. The pits are of varying dimensions, from depressions in which there are small frog-ponds, up to deep hollows exceeding a mile in length. Many of them contain lakes but many, even of the large ones, do not. The several hundred which are large enough to be represented on the map are pretty evenly distributed throughout the plain, but it is reserved for Eureka Township, in the northeast corner of the quadrangle, to display the most striking pitted-plain spectacle. In this locality there is a splendid series of pits, some of them of great size and as much as 100 feet deep. Their steep sides drop rapidly from the plain in which they are sunk, and the bottoms, instead of being flat, or basin-like, are very hummocky.

The region southeast of the Dresser Junction gap is characterized by a topography not usually seen in the midst of an outwash plain. The question arises: Why do great depressions like the basins of East, Horse, Round, and other similar lakes, exist with ground moraine hills between, when even the hilltops are lower than the level of the outwash plain to the north? Horse Lake is but tw miles from the St. Croix moraine, and as low as 960 feet, but its basin has escaped filling by outwash material. Less than a mile northeast of the extremity of the lake flat, the outwash plain ends at the 1,140-foot contour. East Lake is still nearer the moraine, but on the east side of the lake, one mile from the terminal, no stratified drift is found, from the 1,100-foot hilltops to below 1,000 feet, where the hill has been modified by the lake when at a higher level than now.

The reason for this considerable area of ground moraine, almost unaffected by the St. Croix outwash, though at a low level, is found in the established drainage lines. Previous to the outwash deposits, a well-developed drainage channel existed from the Dresser Junction neighborhood, past East and Horse Lakes, following what is now the Horse Creek valley, to the Apple River. When the glacier front stood at the St. Croix moraine, the streams from the melting of the near-by ice quickly collected in this course, producing sufficient volume and velocity to prevent extensive aggradation of the channel. Gathered into one course, the rivulets from the immediate neighborhood did not spread out over the country to the east, whose hills and marshes remained unaltered. However, several miles farther east, in the vicinity of the two Horsehoe Lakes, streamlets from the north, which avoided the Horse Creek drainage system, have been able to spread much farther south, where they have partially filled in the low, marshy areas four and five miles from the moraine.

The Dresser Junction gap.—When the ice stood some distance west of the St. Croix moraine, possibly while at the Franconia recessional, perhaps not so far, the high St. Croix morainic ridge blocked the drainage from the melting ice. As a result, the water ponded between the moraine and the ice-sheet until it rose to the lowest point in the barrier ridge, which happened to be at Dresser Junction, whether by chance, or because of the influence of a pre-Wisconsin channel at this point. Upon reaching the proper height, the overflow cut the barrier down rapidly; for, having dropped most of its load in the ponded portion, the water was relatively clear. The Horse Creek channel was still further eroded and the gap lowered nearly to this level. In later times, when the gray ice advanced to Dresser Junction, its outwash went through the gap. The extensive flat east of Osceola appears to have had its beginning with the ponded waters and outwash from the west.

The Franconia recessional.—The most westerly, and youngest, of the red terminal moraines in the Dalles region, I have termed the Franconia, from the fact that it was first detected on the uplands back of Franconia. It is the most difficult of the three to trace, because most of it has since been rubbed over by the gray ice, which covered what was left with a thin sheet of gray till. As mapped, the chain consists of seven separate links, disconnected by the later ice invasion, but all in a slightly curved strip, whose missing boundaries could easily be drawn. With the exception of the most northerly patch, this moraine lies west of the river in Minnestoa. (See map.) The curved belt is concentric with the two other moraines across the river. In this buried recessional all degrees of terminal topography are displayed, from that which can scarcely be identified, to a strong kettle moraine. Opposite Osceola its great depressions and hummocks have been well preserved; between Taylor's Falls and Franconia station it has been almost entirely obliterated. The veneering of gray drift varies in thickness; on the northernmost strip of this moraine, east of the river, practically no gray till was found, though the presence of limestone pebbles, and also striæ beyond it, proves that this ice once visited that section. Along the railroad tracks, between Taylor's Falls and Franconia, some of the steep banks expose from 20 to 30 feet of gray till, but this is unusual and excessive. The average thickness is perhaps best represented in the strip back of Franconia village, or near Wyckstrom Lake where, in a number of cuts, from 2 to 3 feet of gray drift rests upon the red.

While a strong terminal moraine belt can survive the effects of a subsequent ice advance, and still be recognized by its topography, an outwash plain is much less easily distinguishable under these unfavorable conditions. But by its stratified material it is readily identified. In the road-cuts near Franconia, and from this point south, in the excellent sections revealed by the gullies which are working from the river back into the Minnesota uplands, a thick deposit of stratified sands and gravels is found everywhere to separate the red and gray till-sheets. The lines of contact are sharp. Lithologically, these gravels are the same as the coarse material of the unaltered red drift, from whose ice-sheet they are unquestionably the outwash. Occurring beneath the gray drift nearly everywhere between the Franconia moraine and the river, they belong to the glacio-fluvial work at the Franconia stage. No limestone pebbles are found *in situ* within these deposits, though much limestone frequently has rattled down, as talus, from the gray drift above, and the gravel has often been cemented into a Pleistocene conglomerate by the calcareous waters from the later till-sheet.

In July, 1904, beds of humus material and clay containing pelecypod and gastropod shells, apparently of land types, were reported to have been found between the red till and the stratified drift above, in one of the gullies south of Franconia. In August these beds could not be found. Evidences of slumping were everywhere, induced by the unusually heavy rains of July; possibly the reported interglacial beds had been buried; perhaps they themselves were earlier slumps partially covered with gravel talus. Elsewhere in the same gully, and in the various tributaries where good exposures of the till and outwash gravels could be examined, the contact was clearly marked without any indication of a soil line. The same conditions obtain in the numerous cuts and sections in the strip between the moraine and the river. Vegetable matter and fossiliferous clay, in place, between the red till and red overwash, would mean that, after the unstratified drift was deposited, the ice retreated west far enough and for a time long enough to permit the growth of vegetation and the immigration of mollusks, and that it again advanced, producing the Franconia moraine and the overwash gravels.

West of the Franconia terminal is a gently rolling ground-moraine topography for several miles beyond the boundaries of the quadrangle. Still farther in this direction, a region of many lakes and some moraine belts was seen from the train; but, since the gray drift becomes thicker toward the west, it was not apparent how much of the topography is to be assigned to the red ice. The main fact is that the red glacier retreated toward Lake Superior before the gray ice invaded the region. How far the red had receded by the time the gray appeared, and where the two ice-sheets met, if they ever did come together, are questions which cannot be answered from a knowledge of the St. Croix region alone. Upham[1] reports a soil line between the modified drift (red outwash) and the gray above, as found in several places in Chisago County. This would indicate a considerable interval between the two ice-sheets.

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[1] *Geology of Minnesota*, Vol. II, p. 414.

The story of the rocks.—The hard ledges of Keweenawan trap-rock in the Dalles region exhibit good stoss sides, which furnish strong evidence of the direction of ice movement. East of the river, and especially east of the gray terminal moraine, the planed sides are almost invariably the west or northwest slopes of the ledges, the few exceptions being clearly local accidents. These may be called the red stoss sides; they occur also on the west side of the river, but here the complication of the Kewatin ice is added. Knobs and tails produced from the resisting amygdules in the diabase agree with the story of the stoss sides. Striæ have not been well preserved on these rocks, which in general have weathered sufficiently to destroy the scratches. By looking over a large number of ledges, however, plenty of records can be obtained. The location, direction, and significance of these can best be understood from the striæ map. While there is considerable variation, owing to the fact that they were made at no great distance from the fluctuating edge of the ice, they tell a consistent tale. The striæ are in three sets.

1. The earliest set of scratches discovered affect only a few outcrops above the bend in the river, four and a half miles due north of Taylor's Falls. In a gully whose stream has cut deeply into the drift and laid bare the Keweenawan, striæ reading S. 11° E.[1] and S. 13° E. were found, accompanied by a more marked set running S. 40° E. Half a mile northeast, the hillside ledges bear striæ S. 8° E., S. 11° E., and S. 15° E. As shown on the map, these were probably made when the ice covered the entire quadrangle and was making its terminal moraine at a considerable distance away. The set of striæ next to be described, S. 40° E., are better represented on these rocks, but those of the latest, or third, group are absent, suggesting that the ledges became covered by drift and were protected during the St. Croix terminal stage. This protection may explain the presence of the old striæ which are not found in less favored places. The weak ice of the gray drift, however, has left a still later set of marks

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[1] The directions of striæ are all corrected for magnetic variation.

on the hillside ledges, though those in the ravine which were buried, escaped.

2. The second set of striæ formed by the red ice trend about S. 40° E., with some S. 45° E., and even S. 49° E. These striæ are interpreted as the work of the ice-sheet which had its front at the Alden moraine. This set is the most persistent in the region, suggesting vigorous ice-work at this time.

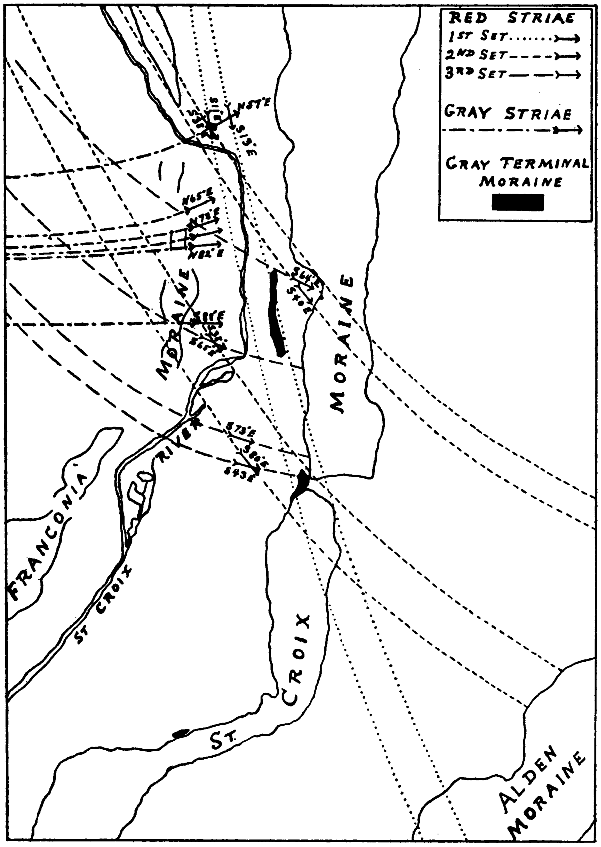

FIG. 3.—Map showing the glacial striæ of the St. Croix Dalles quadrangle

3. The third, and most recent, group of striæ vary from S. 63° E. to S. 80° E., and are thought to have been engraved while the St. Croix moraine was being formed. A comparison of the three sets shows that the first possessed most nearly the direction of main move-

ment; the second, formed as the lateral edge of the ice-lobe came nearer to the rocks in question, deviate about 28° more to the east; while the last, produced near the edge of the ice, trend 30° more to the east. A progressive turning toward the border of the lobe is thus shown. This is in accordance with the law of ice-flow in broad, flat lobes. The general direction of movement of the Lake Superior lobe was southwesterly, but on this, the left flank, its advance was southeasterly toward the ice-edge. The dotted lines on the striæ map are attempts to show this.

Bowlder trains are not of great service as indications of the direction of ice advance in this region, as they are poorly developed. In the lee of only one prominent outcrop—a mile and a half east of Dresser Junction—are the fragments of diabase conspicuous. There bowlders occur in great numbers on the east side of the rock hill.

WORK OF THE KEWATIN GLACIER

Some time after the Superior glacier had withdrawn, the Kewatin sheet, coming down the Red River valley, advanced from the west to the middle of the Dalles quadrangle, spreading its drift over the previous red deposits. This younger drift is strikingly different from the older in several particulars. Its color is a grayish buff, somewhat like that of the drift of southern Wisconsin, though lacking the brownish ferruginous tints. Frequently the surface layer which has been leached exhibits a more yellowish or brownish shade than the unaltered till, due to the oxidation of the iron compounds. While the red drift is sandy, the gray is clayey; the former, as previously noted, contains neither limestone nor shale, both of which abound in the latter. Since much of the western drift is the product of limestone ground up, it follows that it is highly calcareous, except in the upper foot or two where leaching has occurred. The red drift is non-calcareous. Part of the limestone, and most of the dark gray shale which is so characteristic, were probably derived from the Cretaceous strata of western Minnesota and the Red River valley. However, a few Trenton fossils found in the glacial pebbles prove that the Cretaceous series was not the source of at least a part of the limestone in the gray drift.

Gray drift covers all the territory in the quadrangle west of the river, with the exception of some small patches of red drift over which the western ice crept, but either did not leave any débris, or so little that it has since been removed. In Wisconsin it occurs largely in patches, partly because little or no drift was left in some localities, and partly because of stream erosion. East of Osceola this glacier actually reached the St. Croix moraine; from the north of the map to within three miles of St. Croix Falls no gray drift was found on the east side of the river, though striæ interpreted as belonging to the gray ice, and a few limestone pebbles, indicate that the Kewatin glacier visited these parts. As this region was covered only by the extreme edge of the Minnesota glacier, which seems to have been thin, and not to have remained here long, it did not effect a great change in the topography. Some of the hills of red drift were worn down, and many of the depressions filled, but the covering of gray drift is too scanty to mask entirely the old red topography.

The gray terminal moraine.—While the red terminal moraines in this region are all of the recessional type, though large and prominent, the gray moraine is a limiting terminal marking the extreme extension of the sheet, but it is the weakest and most obscure of all. So far as my knowledge goes, the gray terminal first appears at the north within the quadrangle about half a mile east of the river, and a mile north of St. Croix Falls, where it is very indistinct. North of this, on account of the scarcity of gray drift, it has not been recognized. From this point it runs slightly east of south for two miles, becoming a more pronounced ridge; but it cannot be traced beyond the great pit near the railroad tracks, one mile southeast of St. Croix Falls station. From the pit the boundary of the gray till-sheet swings sharply to the west, and then southwest along the slopes of a high veneered rock hill, until it is lost amid Keweenawan ledges, two and a half miles south of Taylor's Falls. Farther south, however, at Dresser Junction, there is a hummocky ridge, though scarcely more than half a mile long, piled up across the front of the great gap in the St. Croix moraine. This is the best-developed portion of the gray moraine. Considering the position of this strip, and the direction of the ridge running from St. Croix Falls south to the great pit, it appears a plausible view that the ice-front at its maximum point stood along a line connecting these morainic strips, approximately where the railroad is today. However, no gray drift was found on the upper part of the hill to the west, which must have been overridden by the ice according to this view, nor has any direct evidence appeared in support of this idea. A further study will be necessary to establish this portion of the border line. South of Dresser Junction the terminal moraine was discovered only in a single isolated spot, three miles southeast of Osceola, where, as is strikingly shown in a road-cut, the ice punched against the red St. Croix terminal, leaving the red and gray till in a dovetail contact. That the limit of the gray ice south of Dresser Junction was the western edge of the St. Croix ridge seems probable.

From so transient an ice advance an outwash plain would not necessarily be expected. In but one place, the Dresser Junction gap, where drainage was concentrated, is gray outwash material seen in any quantity. In the gap not far from the Kewatin moraine at least 10 feet of limestone gravel rests upon the older stratified deposits of the Superior glacier.

The Minnesota upland, except in the belt of the buried Franconia moraine, and at a few points where hills of red drift protrude, in the northwest corner of the quadrangle, is surfaced by a gently rolling ground moraine with abundant marshes and undrained areas. The thickness of this drift sheet is variable; on the hillside, a quarter of a mile west of the picnic grounds in Taylor's Falls, the older red drift appears at the surface in an isolated spot; at the picnic grounds, and also in some of the cuts along the railroad to Franconia station, between 25 and 30 feet of gray till are exposed. As previously stated, 2 or 3 feet is about the mean depth of gray material on the Franconia moraine. The thick sections of gray drift which so greatly exceed the average all occur near the river, suggesting a pre-Kewatin valley or depression favorable to greater accumulation of débris. West of this strip of heavy gray drift along the river—between Taylor's Falls and Franconia—the buried red terminal moraine has been nearly obliterated.

Work upon the rocks.—Instead of the northwest sides of the Keweenawan ledges being planed, as is the case east of the gray terminal, the outcrops west of the river are rounded and polished on the west or southwest slopes. In many cases the work of the red ice is still visible, but the southwest stoss sides, fashioned later, are the more pronounced. These, with the steep drop-off faces on the east and northeast sides, give the general direction of movement, but for more exact data recourse must be had to the striæ. On the hill west of Taylor's Falls the prevailing striæ read in the neighborhood of S. 88° E., showing that the ice moved nearly due east here. In Senator Deedon's yard, a mile and three-quarters to the north, they trend N. 82° E. Farther north, on the opposite side of the road, the following were recorded in order about a quarter of a mile apart: N. 73° E., N. 72° E., and N. 65° E. Across the river, two miles farther north-northeast, scratches were found reading N. 57° E. These varied, but progressively changing, directions put together on the map, show very prettily how the ice of the gray drift spread out near its outer border until, in places it advanced nearly due northeast. On some of the less exposed portions of the *roches* striæ of the Superior ice are still to be seen.

POSTGLACIAL PHENOMENA

Since the Kewatin ice-sheet retreated, the region has undergone some interesting changes, due to erosive action, chiefly that of the St. Croix River. As to what may have been its preglacial course, this region offers little in the nature of a clue. There may have been a preglacial channel past Dresser Junction, and along Horse Creek valley to the Apple River, which lower down empties into the present St. Croix. While the cut between the diabase hills, one and a half miles north of Dresser Junction, was very likely a sluice-way for waters from the melting red ice farther north, to the ponded area, it does not appear to be low enough to form part of a river course before the area just north of it was built up by the thick deposits of drift.

During the early stages of the river's postglacial history, when great floods of water descended the St. Croix from Lake Duluth, much of the flat land east and south of Osceola was temporarily covered, and the already nearly flat area appears to have been still further leveled by sedimentation. Later the river retired to a more definite course which soon deepened. Since the first well-marked course was formed, the stream between Taylor's Falls and Osceola where the most Keweenawan trap-rock was encountered, has migrated westward down the slopes of hard diabase, and cut away the less resistant sandstone and shale. The slopes on the Wisconsin side, opposite

Franconia station for instance, are comparatively gentle, but the Minnesota bank is a steep cliff of Cambrian sedimentaries. A well-developed channel, nearly parallel to the present course and about one mile east of it, can be followed from the bend in the river at the interstate park in Taylor's Falls to Osceola, where it joins the St. Croix today just below Eagle Point. It is not difficult to find the points at which this course was abandoned in the migratory process —first two miles north-northeast of Osceola at a barrier of Keweenawan, next two and a half miles farther upstream at a similar obstacle, again at Thaxter Lake, and lastly at the elbow near Taylor's Falls, where, finding a deep rock fissure, running northeast and southwest, more in line with the new course of the stream below, the opportunity was taken to readjust itself. Some readjustment is evident also above the Dalles in the immediate vicinity of the town of Taylor's Falls.

Terraces.—Objections based chiefly upon the depth of the gorge at the Dalles, and an assumed slowness of erosion through the compact igneous rock, have been raised against considering the canyon to be the work of the St. Croix since the glacial epoch. By Dr. Berkey it has been referred to postglacial erosion. That this is so is evident from a number of considerations. While the river occupied the earlier channel just described, which was long after the ice withdrew, it was cutting the rock barrier of the Dalles at 850 feet, more than 150 feet above the stream-level at this point today. The portion of the Dalles below the bend is still younger. But perhaps the most conclusive and neatest bit of evidence is that furnished by the terraces.

Well-defined alluvial terraces line both banks of the St. Croix above the Dalles, though there are none corresponding to them below the bend in the river, and most of them gradually disappear a few miles upstream. On the Wisconsin side the best benches are at 725 feet, 780 feet, and 810 feet levels; while in Minnesota the most prominent are at 750 feet and 920 feet. There are some correspondencies between the two banks, but, in general, where there are extensive flats on one side, the stream has swept away those opposite. The 750 and 920-foot terraces have small tallying benches across in Wisconsin; but, the 725 and 810-foot flats are not to be found in Taylor's

Falls. Other terraces occur at 880 feet in Taylor's Falls, and 875 feet at its highest point in St. Croix Falls.

The significant feature of these terraces is that none of them is continued below the Dalles. The highest, and that at 880 feet, end against the Keweenawan barrier near the Taylor's Falls schoolhouse; the 750-foot flat, upon which most of the town is built, terminates with the trap-rock in the interstate park; the 875 and 810-foot flats disappear less abruptly on the wooded river banks not far from the diabase ledges; the lowest bench is stopped at the rocks close to the toll bridge. The hard trap-rock at the Dalles acted as a barrier, while the stream above formed a flood-plain. As soon as the falls which developed from the more rapid cutting below the barrier, cut a stope through the barrier and reached the drift above, a trench was quickly cut in the alluvial plain, producing a terrace. At a later time, when the stream-level to the south had lowered sufficiently, falls again developed and produced another terrace; and so on. The pronounced 780-foot terrace, instead of extending upstream from the Dalles, starts with the narrows at the present falls, nearly a mile farther north, where another, but much lower, barrier checked the stream's progress. Falls were therefore here at the time of the formation of that terrace, and with the same reasoning it is safe to predict that the next terrace to appear will be just above the present falls.

The highest of the terraces, at 920 feet, represents approximately the original level of the drift at this point, showing that soon after drainage adopted this course, the igneous rock was encountered, and the stoping process begun; the younger benches, lower upon the slopes of the trench, mark the stages or repetitions of this method of rock erosion with alternate filling and cutting upstream. These post-glacial terraces, intimately associated with, and dependent upon, the receding falls, indicate that the cutting of the deep, but short, gorge in the Keweenawan has all been accomplished by the St. Croix since the retreat of the last ice-sheet.